# Impact of Linear Energy Transfer (LET) on Relative Biological Effectiveness (RBE) Dose in Proton Therapy

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## Introduction

Radiation therapy uses high-energy photon or particle beams to damage the DNA of cancer cells. Among all, Proton therapy is more effective, as protons release a large amount of energy at the target site by forming a peak called as, Bragg peak, resulting in minimal harm to surrounding healthy tissues. This makes proton therapy suitable for treating cancers in sensitive areas like the brain, eyes, lungs, prostate and pediatric cases [1].

In Proton Therapy, as protons pass through the medium, continuously slow down and deposit more energy at end of its path where they stop. This increases Relative Biological Effectiveness (RBE) dose. It is found in various studies that, RBE is influenced by Linear Energy Transfer (LET), tissue type, dose, and biological endpoints. The International Commission on Radiation Units and Measurements (ICRU) recommended a constant RBE of 1.1 for proton beam therapy but notes an increase at the distal edge of the Bragg peak [2]. Therefore, simple analytical calculations of LET are necessary for the exact calculation of RBE.

This paper reviews methods for calculating LET and RBE analytically on existing relations for proton beams of various energies in water, considering parameters like depth, range, and residual range.

## Theoretical Framework

LET is commonly of two types, i.e. Track average LET ($LET_{track}$) and Dose average LET ($LET_{dose}$) [3]. The RBE depends on the proton dose, LET and $\alpha/\beta$ ratio of tissue as [4],

$$\mathrm{RBE}\left(\mathrm{D}, \mathrm{LET}, \left(\frac{\alpha}{\beta}\right)_{\mathrm{phot}}\right) = \frac{1}{2\mathrm{D}}\left(\frac{\alpha}{\beta}\right)_{\mathrm{phot}} + \frac{1}{\mathrm{D}}\sqrt{\frac{1}{4}\left(\frac{\alpha}{\beta}\right)_{\mathrm{phot}}^{2} + \left(\mathrm{q} \times \mathrm{LET} + \left(\frac{\alpha}{\beta}\right)_{\mathrm{phot}}\right)\mathrm{D} + \mathrm{D}^2}$$

Where q is a constant parameter and is taken as 0.434, considering 2 Gy dose (D) and 240 kVp X-ray reference radiation with $\alpha = 0.13\ \mathrm{Gy}^{-1}, \beta = 0.048\ \mathrm{Gy}^{-2}$ (Table 1, Wedenberg, et al.) i.e. $(\alpha/\beta)_{\mathrm{photon}} = 2.708333$ Gy.

LET is computed by using analytical expression given in Ref. [3, 5].

## Results

Dose average and track average LET of energies 150 MeV and 90 MeV, RBE for a particular energy, dose and cell parameter were calculated to observe variation at distal edge. Again, we calculated the mean residual range by using range-energy relationship [6] by developing an algorithm in FORTRAN.

At energies of 150 MeV and 90 MeV track average and dose average of LET along the central axis of the proton beam in water medium, mean initial range (R) are 15.63 cm and 6.33 cm respectively, were calculated for $3.2 \times 10^7$ simulated incident proton of width $\sigma_E$ = 0.5 MeV and residual range ($R_0$) of 2 μm. We observed the variation of LET with depth in Fig. 1 & 2 with entrance values of 0.5 to 1 keV/μm and increases slowly, on approaching mean initial range, rise rapidly to peak value indicating high deposition of dose at target.

Fig.3 describes variation of RBE with LET, initially value of RBE = 1.1 as recommended by ICRU, but at distal edge it increases with LET.

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Further, the variation of RBE with LET, dose and tissue type $(\alpha/\beta)$ as observed RBE rises with LET as shown in Fig. 4.

## Conclusion

The calculation of Linear Energy Transfer (LET) has been done analytically to understand the loss of proton energy during cancer treatment. Here, we found linear variation of the Bragg peak at different incident energies. In clinical treatment, Relative Biological Effectiveness (RBE) for the proton is taken at a constant value of 1.1. Looking into the variation of RBE with LET, we predicted that the RBE is not constant for the cancer treatment which was also analyzed in many references in different content. The variation of RBE with different parameters like dose, LET and tissue type has been studied.

## References


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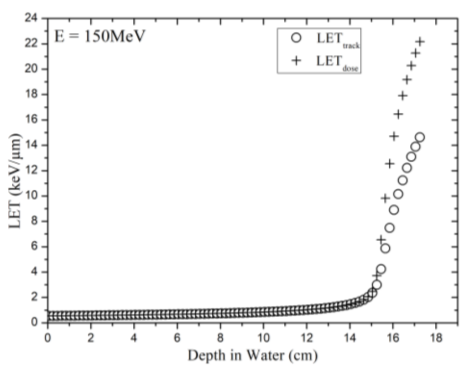


**Fig. 1** Track and Dose average LET distribution of 150 MeV broad proton beam

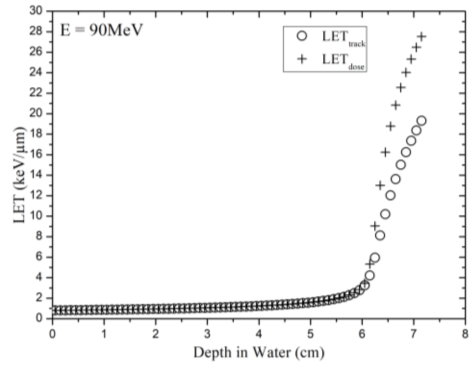


**Fig. 2** Track and Dose average LET distribution of 90 MeV broad proton beam

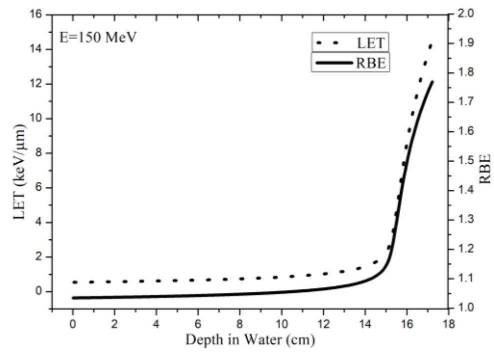


**Fig. 3** Variation of RBE and LET with depth for 150 MeV energetic proton beam of 2 Gy dose and with $(\alpha/\beta)_{\text{photon}}$ = 2.70833 Gy

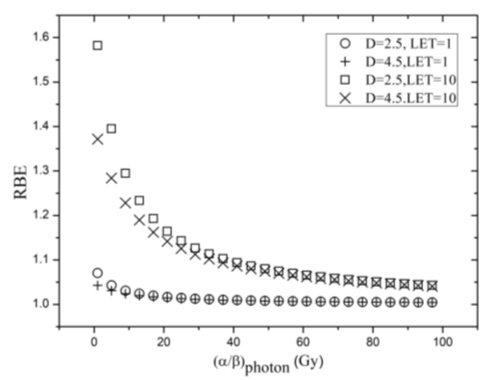


**Fig. 4** Variation of RBE with $(\alpha/\beta)_{\text{photon}}$ for two given doses 2.5 & 4.5 Gy and LET of 1 & 10 keV/μm